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13. ABSTRACT (Maximum 200 words) This study evaluated adding reflective thermal inserts (RTI) to reduce the physiological strain during exercise-heat stress with a radiant load. RTI were used with a U.S. Army desert battle dress uniform, body armor, and helmet. Methods: Four male volunteers attempted four trials (10 min rest followed by 100 min walking at 1.56 m s ⁻¹). All trials were at 40.0°C dry bulb (Tdb), 12.4°C dew point (Tdp), 20% RH, and 1.0 m s ⁻¹ wind speed. On 2 d, there was supplementary irradiance (I) with globe temperature (Tbg) 56.5°C and on 2 d there was no supplementary irradiance (I) with Tbg Tdb. Trial conditions were: 1) RTI and armor with supplementary irradiance (RA_I); 2) plain armor with supplementary irradiance (PA_I); 3) RTI and armor with no supplementary irradiance (RA_I); and 4) plain armor with no supplementary irradiance (PA_I). Results: Endurance times were not significantly different among trials. With one exception, armor and helmet interior and exterior surface temperatures were not significantly different between either RA_I and PA_I or RA_I and PA_I. Temperature on the inside of the helmet in RA_I (47.1 ± 1.4°C) was significantly lower than in PA_I (49.5 ± 2.6°C). There were no differences for any physiological measure (core temperature, heart rate, mean weighted skin temperature, forehead skin temperature, sweating rate, evaporative cooling, rate of heat storage) between either RA_I and PA_I or RA_I and PA_I. Conclusions: Results showed no evidence that wearing RTI with body armor and helmet reduces physiological strain during exercise-heat stress with either high or low irradiance.				
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Reflective Inserts to Reduce Heat Strain in Body Armor: Tests With and Without Irradiance

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Background: This study evaluated adding reflective thermal inserts (RTI) to reduce the physiological strain during exercise-heat stress with a radiant load. RTI were used with a U.S. Army desert battle dress uniform, body armor, and helmet. **Methods:** Four male volunteers attempted four trials (10 min rest followed by 100 min walking at $1.56 \text{ m} \cdot \text{s}^{-1}$). All trials were at 40.0°C dry bulb (T_{db}), 12.4°C dew point (T_{dp}), 20% RH, and $1.0 \text{ m} \cdot \text{s}^{-1}$ wind speed. On 2 d, there was supplementary irradiance (+I) with globe temperature (T_{bg}) = 56.5°C and on 2 d there was no supplementary irradiance (–I) with $T_{\text{bg}} \sim T_{\text{db}}$. Trial conditions were: 1) RTI and armor with supplementary irradiance (RA+I); 2) plain armor with supplementary irradiance (PA+I); 3) RTI and armor with no supplementary irradiance (RA–I); and 4) plain armor with no supplementary irradiance (PA–I). **Results:** Endurance times were not significantly different among trials. With one exception, armor and helmet interior and exterior surface temperatures were not significantly different between either RA+I and PA+I or RA–I and PA–I. Temperature on the inside of the helmet in RA+I ($47.1 \pm 1.4^\circ\text{C}$) was significantly lower than in PA+I ($49.5 \pm 2.6^\circ\text{C}$). There were no differences for any physiological measure (core temperature, heart rate, mean weighted skin temperature, forehead skin temperature, sweating rate, evaporative cooling, rate of heat storage) between either RA+I and PA+I or RA–I and PA–I. **Conclusions:** Results showed no evidence that wearing RTI with body armor and helmet reduces physiological strain during exercise-heat stress with either high or low irradiance.

Keywords: solar load, exercise, core temperature, skin temperature.

MILITARY OPERATIONS during summer months in Afghanistan and Iraq are routinely conducted in hot environments (daytime temperatures $> 32.2^\circ\text{C}$ in Afghanistan and $> 43.3^\circ\text{C}$ in Iraq) with a high radiant heat load (U.S. Army, The modern warrior's combat load: dismounted operations in Afghanistan, U.S. Army Center for Lessons Learned, 2003; and U.S. Army, The modern aviator's combat load: combat operations in Iraq and Afghanistan, U.S. Army Center for Lessons Learned, 2004). During these operations soldiers must wear heavy equipment, including interceptor body armor (IBA) with small arms protective insert plates (SAPI) while performing strenuous physical activity. The combination of clothing and equipment impedes heat loss and increases metabolic costs, accentuating heat strain (9,10).

Military forces have a high interest in innovative products that can be integrated with military clothing and equipment to ameliorate the heat strain induced during these operations. Combat troops in the field are sometimes provided with some of these in an effort to

enhance the quality of their lives during operations in the desert. This equipment is sometimes purchased using individual unit funds, is sometimes purchased by the Rapid Equipping Force for evaluation, and is sometimes provided by the manufacturers as a means to promote their product.

One such set of new products provided to soldiers are the Reflectec™ ballistic vest thermal inserts and helmet liner thermal inserts (RTI) (MSR Industries, Pensacola, FL), which were provided to units in limited quantities for evaluation. Inserts are pictured in the company web site (5). The company literature claims that they are an “innovative radiant/conductive heat reflecting system—without the use of gel packs, external plugs, hoses or other harsh materials currently used to keep peacemakers cool” (5).

Anecdotal reports from troops in Iraq supplied with the RTI indicated that they felt more comfortable on missions when wearing the RTI inside their body armor and under their helmet liners. While the RTI had been worn in the fall when temperatures were not the most severe, the reports created interest in making a large scale purchase of the RTI for troops in Iraq. Prior to recommending the purchase, a request was made to the Natick Soldier Center (NSC) to provide biophysical evaluations on the RTI. NSC performed manikin testing on the RTI to evaluate the impact on insulation when worn in combination with body armor and Kevlar helmet. NSC also requested the U.S. Army Research Institute of Environmental Medicine to perform a biophysical evaluation on a limited number of human volunteers. This technical note details the findings of this human study.

METHODS

Limited biophysical testing of the RTI material on the manikins suggest that it should not significantly change

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insulation (Teal, unpublished data from U.S. Navy Clothing and Textile Research Facility, Natick, MA, 2005; and Endrusick, unpublished data from U.S. Army Research Institute of Environmental Medicine, Natick, MA, 2005). Additionally, data was provided from three tests using American Society for Testing and Materials International (ASTM) methods conducted by independent laboratories for the manufacturer. The ASTM tests all indicated that the RTI could reduce the impact from a radiant source (5). These ASTM findings indicated the possibility that RTI could reduce the radiant heat absorbed by the IBA and transferred to the body.

The current study evaluated the efficacy of RTI in reducing the physiological strain during exercise-heat exposure with supplemental irradiance supplied by an overhead infrared source. The test conditions were designated as: 1) RTI and armor with supplementary irradiance (RA+I); 2) plain armor with supplementary irradiance (PA+I); 3) RTI and armor with no supplementary irradiance (RA-I); and 4) plain armor with no supplementary irradiance (PA-I). Using evidence from the ASTM testing, we hypothesized that inserting the RTI in the +I condition should reduce the expected increases in body core temperature and other physiological parameters caused by the added radiant heat stress.

Subjects

Four male soldier volunteers were recruited as test subjects in this study. Before testing began all volunteers were fully briefed both orally and in writing on the purpose and risks of the study and gave their free and informed, voluntary written consent to participate in the research. Investigators obtained appropriate institutional review board approval and adhered to guidelines established for human research. After a physical examination and medical history review, a medical officer cleared the volunteers as healthy. The mean \pm SD and range for age, height, weight, percent body fat, and body surface area of the four male volunteers were: 21.5 ± 1.9 (20–24) yr, 178 ± 3 (176–183) cm, 86.8 ± 12.6 (75.3–100.9) kg, 17.8 ± 3.9 (13.9–22.4) % body fat, and 2.11 ± 0.14 (1.91–2.23) m².

Procedures/Measurements

Preliminary tests: Preliminary data collection included anthropometric measures of height, weight, and subcutaneous skin fold thickness.

Heat acclimation: Preceding garment tests, the volunteers completed 6 d of exercise-heat acclimation to reduce the physiological strain levels and variability to exercise-heat stress, and for habituation to the experimental methods. The climatic conditions were 40°C dry bulb (T_{db}), 12.4°C dew point (T_{dp}), 20% RH, and a wind speed of $1.1 \text{ m} \cdot \text{s}^{-1}$. Each heat acclimation day, the volunteers were in the environmental chamber for 110 min. They completed two 50-min walks on the treadmill at $1.56 \text{ m} \cdot \text{s}^{-1}$ at a 4% grade [estimated metabolic rate = 400–450 W (7)] with a 10-min rest between the two exercise periods.

Rectal temperature and heart rate were measured

throughout all heat stress procedures. During these sessions, volunteers wore shorts, t-shirts, and athletic shoes. Water was provided ad libitum to prevent excess dehydration during the heat acclimation process. Pre- and post-exercise weights were recorded daily, and after each day's test, volunteers were required to drink sufficient liquid to return within 1% of their first morning weight to assure they did not undergo progressive dehydration.

Experimental trials: The volunteers completed four experimental trials. Each day, volunteers wore underwear, t-shirt, the desert battle dress uniform, socks, boots, IBA with SAPI, and Kevlar helmet with camouflage cloth helmet cover. The IBA was worn over the desert battle dress uniform top. The IBA was designed with an outer camouflage cloth cover, front and rear outer pockets for the SAPI plates, front and rear pockets for Kevlar inserts, and an inner cloth layer. The IBA and Kevlar helmet were placed in the environmental chamber each morning before testing to heat soak, so their starting temperatures would match the environment in which they were tested. The body armor RTI was placed directly behind the Kevlar layer of the IBA, and the helmet liner RTI was placed directly under the helmet's camouflage cover as recommended by the manufacturer.

All tests were conducted at 40.0°C T_{db} , 12.4°C T_{dp} , and $1.0 \text{ m} \cdot \text{s}^{-1}$ wind speed. On 2 d, this environment was maintained with supplementary irradiance (+I) (T_{bg} equal to 56.5°C) and on 2 d it was maintained with no supplementary irradiance (–I) (T_{bg} equal to 40.3°C). The incoming irradiance was also measured on a CNR1 radiometer (Kipp and Zonnen B.V., Delft, Netherlands) with an approximate value of $1200 \text{ W} \cdot \text{m}^{-2}$ during the supplementary irradiance experiments.

Each experimental trial consisted of a 10-min resting baseline period followed by 100 min of continuous treadmill walking at $1.56 \text{ m} \cdot \text{s}^{-1}$, 0% grade. Tests would be stopped if core temperature reached 39.5°C, at the test subject's request, or at the discretion of the investigator or the medical monitor. The metabolic rate during exercise was measured at approximately 25 min into the exercise session. The volunteers were encouraged to drink 300 ml of water provided to them every 20 min to avoid dehydration. Additional water was provided on request. Volunteers were weighed both dressed and semi-nude before and after each test. Pre to post semi-nude weights with corrections for water intake and any urine output were used to calculate total sweat loss in each test. Pre to post dressed weights with the same corrections were used to calculate evaporative heat loss.

During all tests, flexible rectal thermistors (Yellow Springs Instruments, Yellow Springs, OH) inserted 10 cm beyond the anal sphincter were used to measure core temperature. Heart rate was obtained using heart rate watches (Polar Electro Inc., Lake Success, NY). Skin temperatures (T_{sk}) were measured by thermocouples at five sites (head, calf, thigh, forearm, and chest). A mean weighted skin temperature was calculated from the calf, thigh, forearm, and chest (8); the head temperature was reported separately. Heat flow disks with

integrated thermistors (Concept Engineering, Old Saybrook, CT) were used to measure surface temperatures from five locations. Three locations were on the IBA. These were the interior and exterior surface of the IBA and just inside the inner vest pocket behind either the Kevlar (PA+I and PA-I conditions) or RTI (RA+I and RA-I conditions). Two locations were on the Kevlar helmet. These were outside the cloth helmet cover and on the inside surface of the Kevlar helmet.

Rate of heat storage (S) in $W \cdot m^{-2}$ was calculated from the equation $S = [(m_b \cdot c_b)/A_D] \cdot (dT_b/dt)$, where m_b is the mean body weight (kg) calculated from pre and post weights during each garment test; c_b is the constant for specific heat of body tissue ($0.965 W \cdot h^{-1} \cdot ^\circ C^{-1} \cdot kg^{-1}$); A_D is the DuBois surface area (m^2); dT_b is the change in mean body temperature ($^\circ C$) where $T_b = 0.1 \cdot T_{sk} + 0.9 \cdot T_{re}$; and dt is the exposure time (h). Changes are calculated for the total time in chamber for each subject. Change in heat storage is an indicator of the relative overall heat strain induced by the different uniform and environmental configurations. Core temperature and heart rate were also used to calculate the Physiological Strain Index (PSI) (4).

Statistical Analyses

Physiological responses were compared among the four tests. Analyses of variance with repeated measures on the independent variables of armor configuration, environmental condition, and time were used to analyze the dependent variables of core temperature and heart rate. A one-way analysis of variance was used to analyze the dependent variables of endurance time, evaporative cooling, calculated heat storage, and final exercise time values of exterior and interior temperatures of the IBA and Kevlar helmet, mean weighted skin temperature, head temperature, and PSI. When significant values were found in any analyzed data, Tukey's test of critical difference was used for post hoc analysis. Post hoc power analysis using the core temperature results as a primary indicator of heat strain indicated that with the four subjects, the power of the one-way analysis of variance to discriminate among the four conditions was 99% with an alpha of 0.05.

RESULTS

Average metabolic rates were similar during the four trials: RA+I $285 \pm 33 W \cdot m^{-2}$; PA+I $281 \pm 30 W \cdot m^{-2}$; RA-I $273 \pm 24 W \cdot m^{-2}$; and PA-I $269 \pm 33 W \cdot m^{-2}$.

Mean endurance times were similar during the four trials: RA+I 97 ± 12 min; PA+I 102 ± 10 min; RA-I 110 ± 0 min; and PA-I 110 ± 0 min. The shortest endurance time for any volunteer was 81 min in the RA+I test. Therefore, final physiological data are analyzed at 80 min in all four trials. Evaporative heat loss and heat storage are calculated using each volunteer's total exposure time as these variables are corrected for time. These calculations assume linearity in both evaporative heat loss and heat storage during the trials.

Table I shows the mean surface temperature at 80 min for the three IBA locations and the two helmet locations during the four trials. Surface temperatures inside the helmet were significantly higher with supplementary irradiance, and with this supplementary irradiance the PA+I condition ($49.5 \pm 2.6^\circ C$) was higher ($p < 0.05$) than the RA+I condition ($47.1 \pm 1.4^\circ C$) (Table I). There were no other significant differences in surface temperatures between PA+I and RA+I or PA-I and RA-I on the three IBA positions or either helmet position. Skin temperatures on the forehead under the helmet ($n = 3$) were RA+I $38.7 \pm 0.6^\circ C$; PA+I $38.4 \pm 0.6^\circ C$; RA-I $37.4 \pm 0.1^\circ C$; and PA-I $36.6 \pm 0.8^\circ C$. RA+I and PA+I forehead skin temperatures were higher ($p < 0.05$) than RA-I and PA-I. There was no significant difference for forehead skin temperatures between RA+I and PA+I, or between RA-I and PA-I.

Fig. 1 shows mean (\pm SD) core temperature and mean (\pm SD) heart rate over time for the four trials. At 80 min, core temperatures in the four trials were RA+I $38.96 \pm 0.42^\circ C$; PA+I $38.83 \pm 0.28^\circ C$; RA-I $38.32 \pm 0.11^\circ C$; and PA-I $38.37 \pm 0.31^\circ C$. By 55 min, RA+I core temperature was greater ($p < 0.05$) than RA-I and PA-I and by 65 min both RA+I and PA+I core temperatures were greater ($p < 0.05$) than RA-I and PA-I. There was no significant difference in core temperatures between RA+I and PA+I or between RA-I and PA-I at any time. To remove any variability created by differences in initial core temperature, the change in core temperature (δT_{re}) was additionally calculated and the δT_{re} showed the same responses as the 80-min core temperature with no differences between RA+I and PA+I or between RA-I or PA-I at any time.

At 80 min, heart rates in the four trials were RA+I 168 ± 23 bpm; PA+I 160 ± 8 bpm; RA-I 142 ± 12 bpm; and PA-I 148 ± 12 bpm. By 30 min, RA+I heart rate was greater ($p < 0.05$) than RA-I, and at minutes 65, 70, and 80 both RA+I and PA+I core temperatures were greater ($p < 0.05$) than RA-I. There were no

TABLE I. MEAN \pm SD INTERCEPTOR BODY ARMOR (IBA) AND HELMET SURFACE TEMPERATURES AFTER 80 MIN AT FIVE LOCATIONS IN ALL FOUR CONFIGURATIONS.

	Outside IBA ($^\circ C$)	Inside IBA Pocket ($^\circ C$)	Inside IBA ($^\circ C$)	Outside Helmet Cover ($^\circ C$)	Inside Helmet ($^\circ C$)
RA+I	$47.6 \pm 2.1^*$	$39.2 \pm 0.6^*$	$38.9 \pm 0.5^*$	$64.3 \pm 2.1^*$	$47.1 \pm 1.4^*$
PA+I	$46.7 \pm 1.1^*$	$39.2 \pm 0.7^*$	$38.0 \pm 0.6^*$	$62.6 \pm 4.3^*$	$49.5 \pm 2.6^{\dagger}$
RA-I	38.8 ± 0.2	37.4 ± 0.2	37.5 ± 0.3	39.5 ± 0.3	37.7 ± 1.2
PA-I	38.8 ± 0.2	37.6 ± 0.1	37.7 ± 0.2	39.6 ± 0.3	37.9 ± 1.1

RA+I = RTI and armor with supplementary irradiance, PA+I = plain armor with supplementary irradiance, RA-I = RTI and armor with no supplementary irradiance, and PA-I = plain armor with no supplementary irradiance.

*Significantly greater than RA-I and PA-I ($p < 0.05$).

† Significantly greater than RA+I, RA-I, and PA-I ($p < 0.05$).

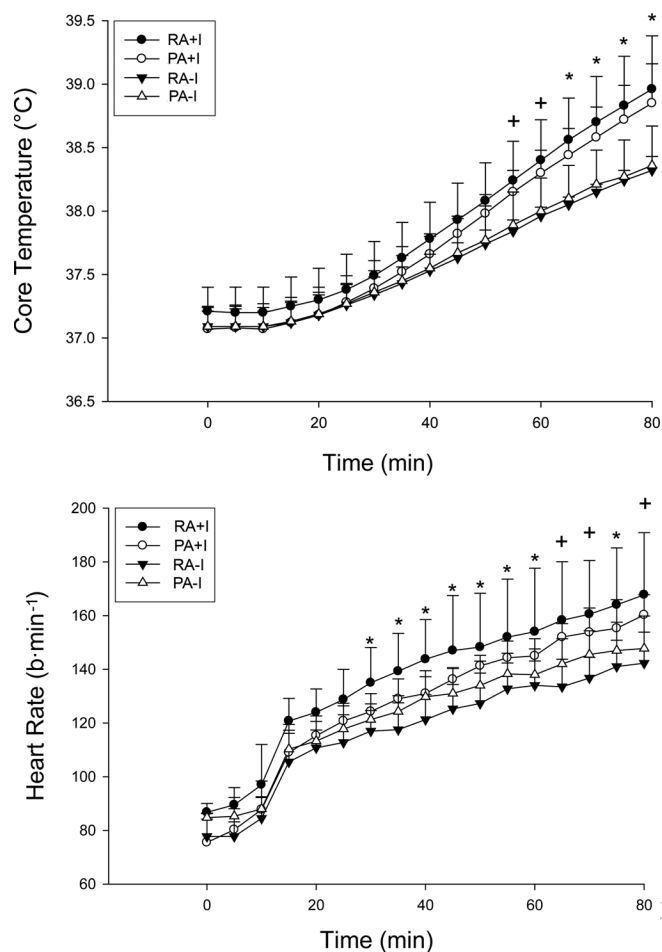


Fig. 1. Mean core temperatures and heart rates across time in all four configurations: RTI and armor with supplementary irradiance (RA+I); plain armor with supplementary irradiance (PA+I); RTI and armor with no supplementary irradiance (RA-I); and plain armor with no supplementary irradiance (PA-I). On core temperature graph (top), + indicates RA+I significantly greater than RA-I and PA-I ($p < 0.05$); and * indicates RA+I and PA+I significantly greater than RA-I and PA-I ($p < 0.05$). On heart rate graph (bottom), * indicates RA+I significantly greater than RA-I ($p < 0.05$); and + indicates RA+I and PA+I significantly greater than RA-I ($p < 0.05$).

significant differences in heart rates between RA+I and PA+I at any time or between RA-I and PA-I at any time. No significant differences were observed among the four trials in any of the responses calculated from physiological measurements (S, PSI, mean weighted skin temperature, and evaporative heat loss).

DISCUSSION

This study showed no evidence that adding RTI to the IBA and the helmet reduced heat strain in soldiers working in an environment with a significant radiant heat load. Literature provided by the RTI manufacturer indicated that the inserts block energy absorption or transfer by both reflection and conductance (5). In general, it is difficult to separate heat exchange via the two pathways. The mechanisms for energy transfer may differ in importance relative to the placement of the RTI within the clothing ensemble. The performance of the RTI near the helmet surface may differ significantly from the same materials inside body armor. It should

also be noted that previous research on the impact of radiant heat has shown that approximately $700\text{--}900\text{ W} \cdot \text{m}^{-2}$ of natural incoming radiation on both nude and dressed bodies contributed only $100\text{--}170\text{ W}$ of radiant heat load to the overall heat balance with no supplemental radiant barriers in place (1,6). So the impact of the RTI might be less than indicated by the manufacturer.

Typically, reflective radiation barriers are placed with a reflective layer facing the radiation source, usually on the outside surface to minimize any absorption of radiant energy. However, a highly reflective and easily detectable outer surface is not desirable during military operations. Therefore, as directed by the manufacturer, the RTI inserts were placed within the clothing or armor layers, a placement which was more analogous to radiant barriers placed within building insulation (3). The greatest value of radiant barriers placed within building walls and roofs is observed when there is an air space on both sides of the radiant barrier so that the predominant mechanism for heat exchange in that space is radiant (rather than by convection or conductance), which can be reflected by the barrier (3). However, the RTI material inserted into the IBA was placed so that it was in contact with both the inner rip stop nylon surface of the soft Kevlar inserts on the outside and the nylon cordura inner fabric layer of the IBA on the inside with little or no air space. With this placement, the primary heat transfer to the RTI would be through conduction from both external and internal heat sources negating any reflective benefit that could be provided by the product. The only potential benefit of the RTI in this placement would be as an insulative barrier. However, the dense materials in both the Kevlar and SAPI plates already create a significant insulative barrier to heat gain from the environment, minimizing any impact that the RTI might have.

The lack of any observed surface temperature differences between either RA+I and PA+I or RA-I and PA-I within the body armor on the torso indicates the RTI barrier had no net impact on the heat transfer under these test conditions. This conclusion is supported by the physiological data, which also showed no differences. A typical variation in core temperature among subjects is about 0.2°C (2). A reduction in core temperature of twice that variation or approximately 0.4°C with the RA+I relative to the PA+I would likely have been physiologically significant. It is possible that this reduction would have reduced the cardiovascular strain under these experimental conditions. However, results showed an increase of 0.13°C (within the expected variation) with RA+I relative to PA+I. These findings indicate there was no significant insulation provided by the RTI on the torso.

The RTI material inserted into the helmet was in contact with the outside cotton camouflage helmet cover and with the Kevlar helmet on the inside. However, unlike the IBA on the torso, the temperature measured under the helmet with supplementary irradiance was slightly but significantly lower with the RTI. In addition, while not statistically significant, with the RTI in place, the temperature on the outside of the helmet

cover was slightly higher (64.3°C) than without the RTI (62.6°C). It is possible that because of the placement of the RTI beneath the thin cloth helmet cover that it served as an insulating layer to prevent energy transfer to the Kevlar, so that more heat remained in the cover material. This possibility would result in a significantly lower temperature measured against the inside of the helmet. However, it should be noted that while the mean temperature on the inside of the helmet in the RA+I condition (47.1°C) was statistically lower than the temperature on the inside of the helmet in the PA+I condition (49.5°C), this difference had no impact on the mean forehead skin temperature, which was not significantly different between the RA+I (38.7°C) and PA+I (38.4°C) conditions.

Conclusion

While the exact mechanisms that operate within the various clothing layers cannot be wholly described or differentiated, the physiological data indicate that the RTI neither improved nor degraded the thermal state of the volunteers under the test conditions. Based on these findings, it is unlikely that the RTI would provide any real benefit to soldiers.

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The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the Army or the Department of Defense. Any citation of commercial organizations and trade names in this report does not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

Investigators adhered to AR 70–25 and USAMRMC Regulation 70–25 on the use of volunteers in research, and the research was conducted in adherence with the provisions of 45 CFR Part 46.

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